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Functional Specification

INNER TRIPLET QUADRUPOLE HELIUM VESSEL LMQXB AND CRYOSTAT ASSEMBLY LQXB

Abstract

This specification establishes the functional requirements for the LMQXB helium assembly, and the fully cryostatted LQXB assembly. These elements compose the Q2 inner triplet optical element at interaction regions 1, 2, 5 and 8.

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1. OVERVIEW

The LQXB cryostatted assembly forms the as-installed Q2 optical element in the 4 interaction regions of the LHC, shown in Figure 1 and as described in the Inner Triplet Functional Specification [1]. The 3 magnetic elements of the Q2 optical element are two MQXB quadrupoles [2], and a steering dipole corrector MCBX [3], which are contained within the LMQXB helium vessel. The LMQXB, when surrounded by cryostat shields, piping, and the vacuum vessel, is then the LQXB assembly, as installed in the tunnel of the LHC.

In addition to the LQXA, LQXB, and LQXC assemblies, kits to complete the Q1/Q2 and Q2/Q3 interconnects will be installed in the LHC tunnel to complete the inner triplet system.

The MQXB design and production is the responsibility of Fermilab. The MCBX dipole corrector and beam tube are delivered from CERN. Fermilab is responsible for the design and assembly of the LMQXB vessels, and the LQXB cryostat assemblies. The interconnect assembly, with the exception of the cold bore and cold bore associated components, is the responsibility of Fermilab, though it and the the beam position monitor mounting will occur only at CERN. Interface definitions for the MQXB and MCBX magnetic elements can be found at [4] and [5], respectively.

A cross section of the LQXB assembly is shown in Figure 2.

This functional specification covers the LMQXB and LQXB assemblies only.

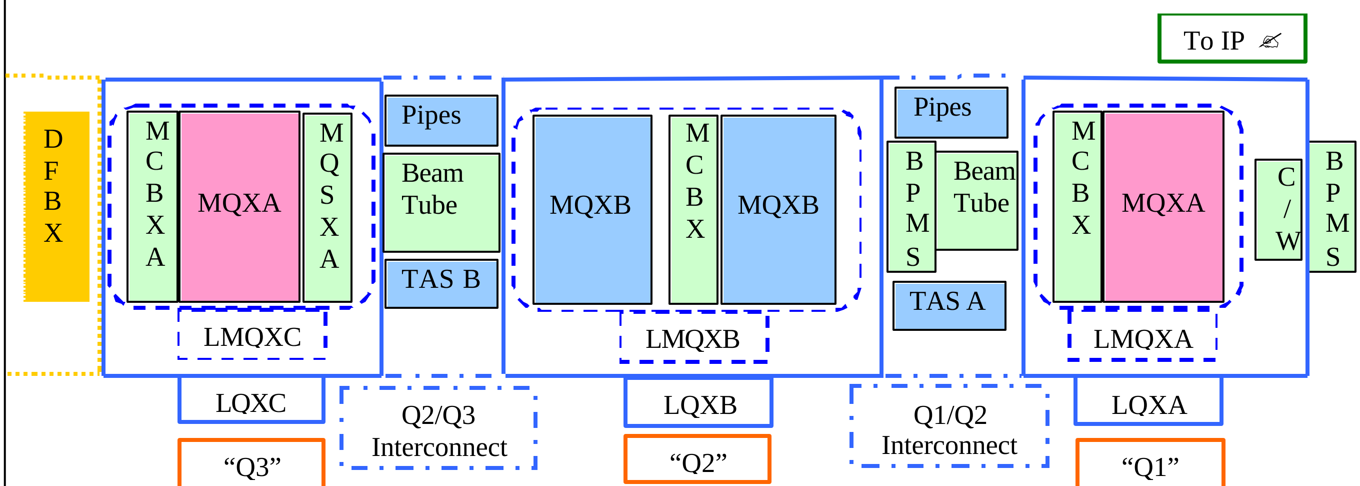

Figure 1. Inner Triplet Nomenclature.

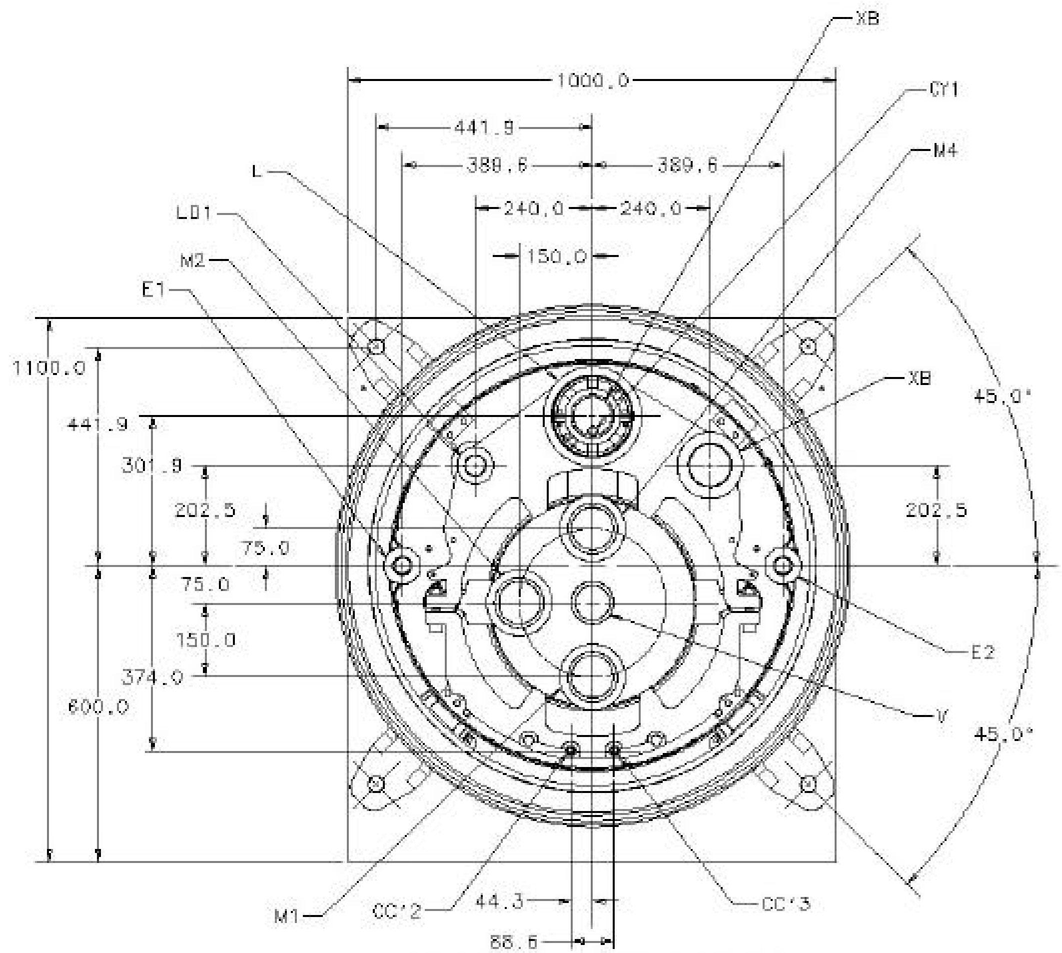

Figure 2. LQXB end view, looking toward the IP from the non-IP end.

2. LMQXB 1.9K HELIUM VESSEL

The LMQXB assembly aligns the 3 magnetic elements MQXB, MCBX and MQXB; completes the enclosure of the elements in a 1.9K helium vessel; provides means for routing all wires, leads and bus work from within the LQXB and those passing through from the LQXA assembly; and allows for insertion of a continuous cold bore through the assembled elements.

2.1 ALIGNMENT REQUIREMENTS

The required relative alignment of the magnetic elements is defined in the Alignment Reference Table, initially generated and reviewed at the Inner Triplet Alignment Worshop in October 1999 [6]. The pertinent criteria for the LMQXB assembly are extracted from the reference table and included here in Table 1. All values shown are for the average magnetic axes of each individual magnetic element. The MCBX axis is referenced to the MQXB closest to the IP in the assembly. In the case of the MQXB, the values are checked by single stretched wire measurements. For the MCBX, alignment reference points provided by CERN on the assembly are used.

Table 1 LMQXB Magnetic Alignment Requirements

Tolerance – MQXB to MQXB	***Value***
Transverse Offset	500 microns
Relative Roll	1 mrad (rms)
Relative Pitch / Yaw	0.1 mrad
Tolerance – MCBX to MQXB	***Value***
Transverse Offset	500 microns
Relative Roll	5 mrad (rms)

2.2 CRYOGENIC REQUIREMENTS

The LMQXB design provides a 1.9K helium vessel, designed and pressure tested for a rated internal pressure of 20 bar. In addition, the vessel provides adequate pipe cross sectional area in the intermediate connection to the external heat exchanger, and in the 3 interconnect pipes, for transport of the heat loads to the 1.9K 2-phase helium flow such that the magnets are maintained at proper operating temperatures.

The LMQXB is a pressure vessel, and is designed and documented in accordance with CERN and USLHC agreements [7].

2.3 ELECTRICAL / INSTRUMENTATION REQUIREMENTS

All wiring internal to the LMQXB assembly is routed back through the assembly and the inner triplet to the DFBX. In addition, the LMQXB assembly provides space for routing of all wiring from the LMQXA assembly back to the DFBX. This includes main and corrector bus work, voltage tap wires, quench heater leads, warm up heater leads, and thermometry wiring. A complete tabulation of the wires passing through the LMQXB is show in Table 2 and in reference 4.

Table 2 LMQXB Electrical Components

LMQXA Originating Item	***Qty***	***Description***
Main Bus	2	Stabilizied MQXB inner cable
Corrector Bus	4	2.5mm x 1.7mm monolithic bus
Voltage Taps	8	26 gauge polyimide coated wire
Temperature Sensor Leads	8	30 gauge polyimide coated wire
Warm Up Heater Leads	4	20 gauge polyimide coated wire
Quench Heater Leads	4	20 gauge polyimide coated wire
LMQXB Originating Item	***Qty***	***Description***
Main Bus	2	Stabilizied MQXB inner cable
Corrector Bus	4	2.5mm x 1.7mm monolithic bus
Voltage Taps	14	26 gauge polyimide coated wire
Temperature Sensors	16	30 gauge polyimide coated wire
Warm Up Heaters	8	20 gauge polyimide coated wire
Quench Heaters	8	20 gauge polyimide coated wire

The wires are provided with a fixed point in the center of the LMQXB assembly. Expansion loops are provided as needed in the end domes of the assembly.

2.4 COLD BORE

The cold bore [8] is provided by European industry through CERN for insertion in the completed LMQXB assembly. The cold bore is centered in the MQXB magnets by contact with the ground insulation that covers the pole of the collars in the magnet assembly.

The cold bore is terminated with a flange at either end of the end domes of the LMQXB. These flanges provide an attachment point for the beam screen assembly in the Q2/Q3 interconnect and the BPMS in the Q1/Q2 interconnect.

3. LQXB CRYOSTATTED ASSEMBLY

The completed LMQXB assembly is surrounded by pipes, shields, and the vacuum vessel to complete the LQXB cryostatted magnet assembly [9] which is installed in the tunnel.

3.1 ALIGNMENT REQUIREMENTS

From the reference alignment table [6], the requirements for placement of the LQXB in the tunnel are as shown in Table 3.

Table 3 LQXB Magnetic Alignment Requirements

Installation Tolerance	***Value***
Transverse Offset	300 microns
Roll Angle	0.1 mrad
Longitudinal Displacement	3 mm

However, within the LQXB what is measured by the single stretched wire system is the average magnetic axis (cold) relative to external fiducials on the cryostat vacuum vessel. The requirements for the transverse, rotational, and longitudinal alignment of the LMQXB in the LQXB are therefore driven by the allowable pipe offsets which can be accommodated during final installation of the LQXB in the inner triplet. Typically, this limit is determined by the allowable offset of the outermost bellows in the assembly, that associated with the thermal shield. Table 4 shows the alignment requirements for the LMQXB within the LQXB.

Table 4 LMQXB to LQXB Alignment Requirements

Item	***Value***
Transverse Offset	500 microns
Roll Angle	5 mrad
Longitudinal Displacement	5 mm

3.2 CRYOGENIC REQUIREMENTS

The LQXB is part of an integrated inner triplet cryogenic system. An example of this system is shown in Figure 3, for high luminosity IR5L. Though the cryogenic system has small variations depending on installation location (uphill or downhill, high or low luminosity), each delivered LQXB includes piping such that the unit can be installed at any of the locations. Installation differences are described in the interface specification.

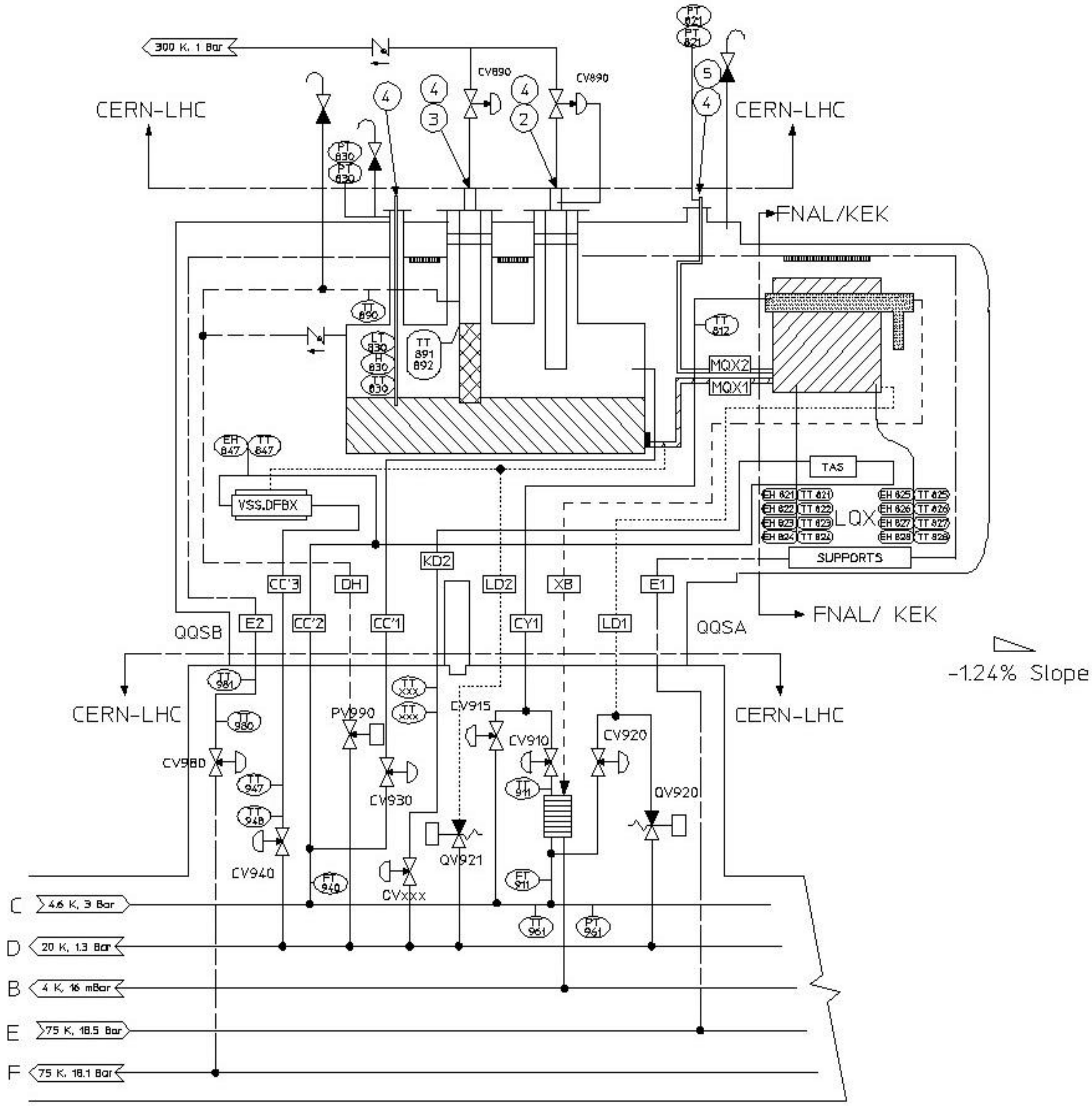

Figure 3. Simplified Flow Schematic for IR5L

All piping is run internal to the LQXB cryostat, and a complete list of pipes with their nominal design parameters included in each cryostat is listed in Table 5.

Table 5 LQXB Piping

Line	*Description*	*IP*	*Qty*	*Pmax*	*T(K)*	*Flow(g/s)*
XB	Pumping Line	All[1]	1	4 bar	2	8.6
LD	Cooldown Line	All	1	20	2	30
	Ht Exch. Outer Shell	All	1	20	2	0
XB	Ht. Exch. Inner tube	All	1	4	2	8.6
CY	Ht. Exch Lhe Supply	1L, 2L, 5R, 8L	1	4	2	8.6
M	Cold Mass Connections	All	3	20	2	0
CC	4.5K supply	1L, 1R, 5L, 5R	1	20	5	1.1
CC	4.5K return	1L, 1R, 5L, 5R	1	20	5	1.1
E	50 K Shield Supply	All	1	22	60	5
E	50K Shield Return	All	1	22	65	5

1 – The external pumping line XB is installed in all LQXB assemblies. However, at installation only those at IPs 1R, 2R, 5L, and 8R are connected for use.

The estimated static heat loads of the LQXB assembly are shown in Table 6.

Table 6 LQXB Estimated Static Heat Load

Temperature	*Heat Load*
50 K	90 W
5 K	0 W
2 K	7.5 W

3.3 ELECTRICAL / INSTRUMENTATION REQUIREMENTS

As previously mentioned, all wires originating inside the LMQXB 1.9K Helium Vessel remain in the vessel and are routed back through the inner triplet to the DFBX.

For the LQXB, the only additional wires are from the BPMS at the Q1/Q2 interconnect, and these lead wires are run through the vacuum vessel interconnect region for external connection.

3.4 VACUUM

Insulating vacuum pump out ports and relief valves are located in the vacuum vessel sleeves at each of the Q1/Q2 and Q3/Q3 interconnects.

3.5 RADIATION ENVIRONMENT

The inner triplets of the LHC are subjected to extremely high radiation loads due to secondaries from the pp-interactions, particularly at the high luminosity interaction points 1 and 5. The actual dose rate depends on the location of the magnet, and varies strongly within each individual magnet in both azimuth and longitudinal position. The maximum dose rate along the LQXB in IP 1 and 5 is at 43 m from the interaction point at the coil mid-plane. Table 6 summarises the peak yearly-integrated dose expected [10] to be deposited in the inner coil straight section, where the dose is maximum, at the outside diameter of the LMQXB vessel, and at the outer radius of the vacuum vessel for the LQXB. The peak dose rates in the coil and end parts are averaged over 20 degrees in azimuth. The annual dose is calculated based on the assumption that the LHC operates for 200 days per year at an average luminosity which is 50% of the nominal luminosity of $1\times10^{34}\,cm^{-2}sec^{-1}$.

The material limitations are taken from [11]. The least radiation tolerant material used in the magnet is G11CR, which is used in the coil end parts and in the collet assemblies that provide mechanical support to the coil ends. The radiation lifetime of the MQXB quadrupole is expected to be limited by the end part material, whose mechanical properties are degraded by 50% after an integrated dose of approximately 20 MGy. At the dose rate given in Table 7, this corresponds to approximately 7 years radiation lifetime.

Table 7 Expected yearly radiation dose at nominal luminosity in IP1/5 as a function of radial location.

Radial Location	***Interaction Region***	***Dose, MGy/yr***
Inner coil straight section	IR1/5	3.9
LMQXB vessel	IR1/5	xx
Vacuum Vessel	IR1/5	0.006

4. RELIABILITY REQUIREMENTS

4.1 LIFETIME

The quadrupoles are expected to survive approximately 7 years of LHC operation under nominal luminosity conditions, limited primarily by the integrated radiation dose to the materials in the coils. To extend the useful life of the magnets beyond this, the inner triplet assemblies may be interchanged between the low luminosity and high luminosity IPs. The number of thermal cycles, powering cycles, and quenches required over the expected lifetime of the LHC machine are shown in Table 8.

Table 8 Required lifetime parameters.

Item	***Value***
Number of Thermal Cycles	25
Number of Powering Cycles	12,000
Number of Quenches	10

4.2 SPARES

A complete and fully tested LQXB cryoassembly will be delivered to CERN as a spare. The spare will include a kit of field added parts necessary to allow it to be installed in any location.

5. SHIPPING

Completed LQXB assemblies will be shipped to CERN for insertion in the LHC tunnel. Main parameters of the assembly are shown in Table 9 [12]. Installation of the magnet in the tunnel is the responsibility of CERN, who will mount the LQXB on CERN designed and installed jacks in the LHC tunnel.

Table 9 LQXB Shipping Information

Item	***Value***
Mass	17455 kg
Length	13143.9 mm
Nominal Diameter	914 mm
Maximum cross section	1000 mm x 1100mm

6. CERN PROVIDED / INSTALLED PARTS

CERN provides MCBX magnets, beam tubes, warm up heaters, instrumentation wiring, cold mass temperature sensors, and corrector bus to Fermilab for completion of the LQXB assembly.

In addition, Fermilab will supply to CERN for installation by CERN an interconnect kit [zz], consisting of the piping, shield bridges, insulation, and other components necessary for completion of the inner triplet assembly in LHC, except as noted below.

CERN has agreed to provide several components to be installed in the MQXB quadrupole to ensure compatibility with CERN data acquisition and control systems. These are listed in Table 10. These will be provided for the planned two full-scale prototype MQXB as well as for the production magnets.

Table 10 CERN provided parts

Item	***Quantity***
MCBX	9
Q2 Beam Tube	15
Quench Protection Heaters	84
Corrector bus	1.0 km
Instrumentation wire 20 Gauge	2.5 m
Instrumentation wire 26 Gauge	10.0 km
	0.6 km
Thermometer cable (4 30 Gauge)	
Temperature Sensors	42
Vacuum Bellows Assemblies (for Q1/Q2 and Q2/Q3 interconnects)	18

CERN will supply and install the BPMS, active beam screen as needed, and the components associated with the cold bore region in the interconnects of each inner triplet.

7. LIST OF INTERFACES

Tunnel Floor
Alignment
Q2/Q3 Interconnect Kit
Q1/Q2 Interconnect Kit (including BPMS)

8. REFERENCES

[1] LHC Engineering Specification, "Inner Triplet Systems at IR 1, 2, 5, and 8," LHC-LQX-ES-0001.

[2] LHC Functional Specification, "Inner Triplet Quadrupole MQXB," LHC-LQX-ES-0002.

[3] LHC Specification, "Supply of Superconducting Dipole Corrector Magnets MCBX for the Inner Triplets of the Large Hadron Collider," LHC-MCBX-CI-0001, with updates in Change order LHC-MC-EC-0001.

[4] LHC Interface Specification, "Inner Triplet Quadrupole MQXB," LHC-LQX-ES-0003.

[5] LHC Interface Specification, "Inner Triplet Corrector MCBX/MCBXA," LHC-LQX-ES-0005.

[6] IR Quadrupole Reference Alignment Table, http://www-ap.fnal.gov/lhc/meetings/workshop99.html.

[7] CERN/LHC – US/LHC MOU ON ACCELERATOR MECHANICAL SAFETY, TIS-TE-MB-98-74

[8] Supply of Beam Tubes for the LHC Inner Triplet, 5520-ES-390040

[9] LHC IRQ Cryostat Q2 Interface and Assembly, FNAL Drawing number 5520-ME-390266

[10] N. Mokhov, "Radiation Deposition in the LHC Inner Triplets at Nominal Luminosity", in preparation (insert Nikolai's latest and greatest numbers and reference…ip prep!).

[11] I. S. Baishev, A.I. Drozhdin, and N.V. Mokhov, "Beam Loss and Radiation Effects in the SSC Lattice Elements," SSCL-306, November 1990;
H. Schönbacher et al, "Results of Radiation Tests at Cryogenic Temperature on Some Selected Organic Materials for the LHC," CERN 96-05.

[12] LHC IRQ Cryostat Q2 Lifting and Transport Interface, FNAL Drawing number 5520-ME-390298